Vertex Detector Upgrade Plans for the PHENIX Experiment at RHIC

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Abstract

The PHENIX experiment at the Relativistic Heavy Ion Collider presently performs its third data taking run. During the last shutdown, the final components of its baseline detector were installed. PHENIX is now fully instrumented. It is expected that the collider will reach full luminosity with heavy ion and polarized proton beams by the year 2006. An upgraded collider is intended for the second half of the decade, with a luminosity increase to about 20-40 times the design value of 8×10^{26} cm^{-2}s^{-1} for Au+Au and 2×10^{32} cm^{-2}s^{-1} for polarized proton beams. Collision energies will increase from $\sqrt{s_{NN}} = 200$ GeV to $\sqrt{s_{NN}} = 500$ GeV. The PHENIX collaboration plans to upgrade its experiment to exploit new physics in reach with an enhanced detector. A silicon vertex detector comprising pixel and microstrip sensors in a new vertex spectrometer is the main new sub-system discussed.

Key words: RHIC, PHENIX, Upgrade, Silicon Vertex Detector, Microstrip, Pixel
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1 Introduction

The PHENIX experiment [1] is the large experiment at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) that was specifically designed to detect probes which sense the early phase of heavy ion collisions. It is expected that the formation of Quark Gluon Plasma (QGP), a high-energy-density state of matter with freely moving quarks and gluons never clearly observed but believed to have existed in the early universe when hadrons formed about 10 μs after the Big Bang, is most likely to occur then. The probes of interest for the study of Quantum Chromo Dynamics (QCD) and the questions of confinement of color charge in hadrons and the absence of chiral symmetry in nature, are electromagnetic radiation, jets of particles with

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high transverse momenta, and charmonium states from heavy flavor decays. Another physics programme at RHIC with polarized proton beams aims at the understanding of the complex internal spin and flavor structure of hadrons. For polarized proton physics, especially jet production, prompt photons and Drell-Yan lepton pairs provide information on the parton kinematics.

2 The PHENIX Experiment

The design and construction of the PHENIX experiment reflects the requirement of high-rate capable detector systems to measure rare electromagnetic probes over a large momentum range and with high mass resolution. The experiment comprises four spectrometers. A pair of "central" spectrometers covers mid-rapidities ($|\eta| < 0.35$, 2×90 degrees of azimuth) and enables charged-particle tracking with drift chambers and pixel pad chambers, electron and photon identification with ring imaging cherenkov counters and time expansion chambers, hadron identification via time-of-flight measurement in a scintillator wall, and energy measurement in two types of electromagnetic calorimeters. In the central region an axial magnetic field is created by two sets of solenoidal coils enabling momentum measurement with the central tracking detectors. Two muon spectrometers are located at forward rapidities ($1.2 < |\eta| < 2.2$). They consist of a hadron absorber, a muon tracker with radial magnetic fields and muon identifier stations. A multiplicity vertex detector measures the charged particle multiplicities and the position of the event vertices along the beam line. Beam-beam scintillator counters, zero-degree calorimeters and scintillator multiplicity counters allow to characterize the collisions and to trigger the data collection from the PHENIX sub-systems.

3 From RHIC I to RHIC II

Two physics runs have been performed since the start-up of RHIC in Fall 1999. They yielded already numerous PHENIX results [2]. The third data taking period at RHIC has just started. The PHENIX baseline detector systems are now completed and enable the collaboration to exploit the presently ongoing first phase of RHIC that focusses on the confirmation of QGP creation in heavy ion collisions. A second phase of RHIC is anticipated to begin during the second half of this decade, with a luminosity increase to up to 40 times the design value in an upgraded collider. It will focus on the fundamental properties of QCD. A key requirement of that program will be the access to new observables, for which upgraded PHENIX detector systems are needed that add new capabilities to the baseline experiment [3].
This situation shall be illustrated in Fig. 1 which shows an example of the present central spectrometers' track and vertex reconstruction capabilities along with one of the important recent PHENIX measurements. While the tracking detectors can handle well the particle multiplicity even in central Au+Au collisions and reconstruct the trajectories and momenta of the charged particles produced, and particle identification is performed in addition to the

tracking, the vertex measurement based on the information from the multiplicity vertex detector, the beam-beam counters and the reconstructed tracks themselves is not of sufficient resolution to distinguish fine details that can reveal the source of the particles produced. The measurement of open charm and open beauty as well as the total charm and bottom production belongs to the very important measurements of leptonic observables in heavy ion collisions. Their direct detection, never achieved so far, requires the identification of secondary vertices of charm and beauty meson decays, i.e. track reconstruction with spatial resolution of the order of a few tens of microns at the collision vertex. With the baseline detector, only indirect detection of electrons from such sources is possible. PHENIX performed two measurements of electron production from non-photonic sources, once subtracting the vast background using a Monte Carlo “cocktail” simulation of all known electron sources, and the other time calibrating the background with an intentionally added photon converter of known thickness and the π^0 Dalitz decay rate measured in PHENIX itself, which is the dominant background source for electron production through photon conversion in the detector material [4]. The measured electron spectra are in good agreement with expected charm production. Future direct measurements will have to confirm the result and are required to separate the contributions of charm and beauty to the electron production at higher transverse momenta.

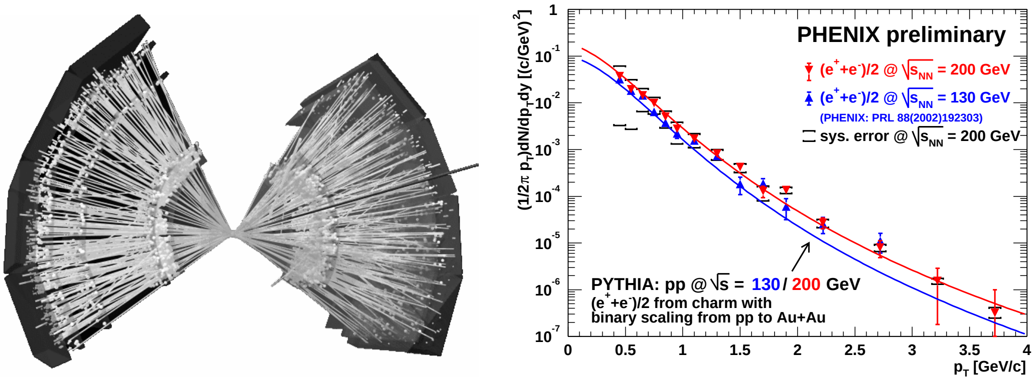

Fig. 1. Tracks of charged particles produced in a central Au+Au collision at $\sqrt{s_{NN}} = 200$ GeV, reconstructed in the central spectrometers of PHENIX (left). Two indirect measurements of electron production from non-photonic sources in min. bias Au+Au collisions using the PHENIX central spectrometers. The measurements are compared with expectations from semi-leptonic D meson decays (right).

4 Upgrade of PHENIX with a Vertex Detector and Spectrometer

The main PHENIX upgrade foreseen is a new vertex spectrometer that will be installed in the space presently used by the multiplicity vertex detector. It combines a flexible field configuration, high precision vertex tracking in the central and forward regions to measure jets and to detect heavy-flavor decays, with electron identification and tracking. Figure 2 shows the spectrometer with its three sub-systems between the pole faces of the central magnet. A fast and

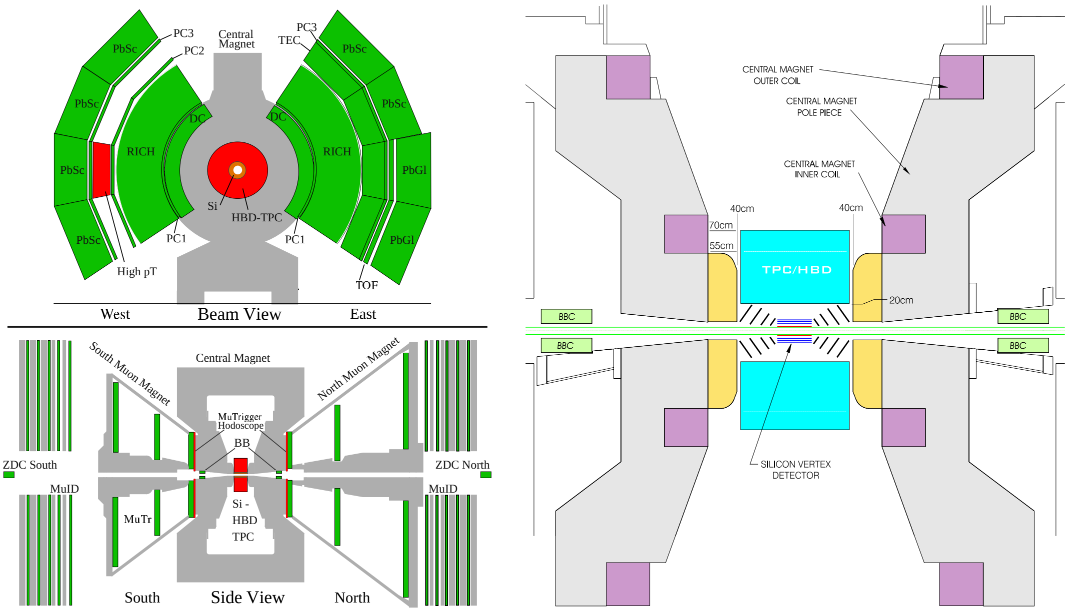

Fig. 2. The planned Vertex Spectrometer in PHENIX.

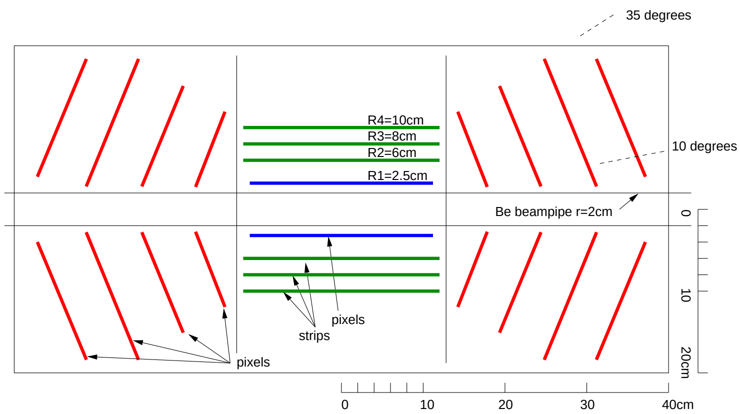

Fig. 3. Schematic layout of the proposed Silicon Vertex Detector, indicating the approximate positions and dimensions of the barrel and end-caps detector layers.

compact time projection chamber combined with a hadron blind detector is foreseen to track and identify electrons over the full azimuth. The inner pair of magnet coils, already foreseen in the design of PHENIX and installed between Run-II and Run-III, can create a low-field environment so that low-momentum electrons (p $<$ 200 MeV) produced in Dalitz decays and conversions, not detectable in the central spectrometers, remain in the vertex spectrometer acceptance and can be rejected. The vertex tracking will be based on highly segmented silicon pixel and microstrip detectors at mid-rapidity, and further silicon pixel detectors in the forward direction. The schematic layout of the vertex detector is shown in Fig. 3. The central silicon detectors (consisting of an internal layer pixels and three outer layers strips) will cover approximately $-1.2 < \eta < 1.2$ and, arranged in two half-shells, almost 2π in azimuth. The

forward detectors (four pixel cones per side) match the geometrical acceptance of the muon spectrometers and will cover $1.2 < |\eta| < 2.7$.
An extensive research and development effort was initiated in the PHENIX collaboration to identify the most effective technologies for the new detector systems in order to achieve the envisaged physics performance both in runs with heavy ion and polarized proton beams. High occupancy in the internal barrel layer requires the use of pixel detectors. Microstrip detectors can be used in the more outward layers. Challenging is the necessity for thinnest possible detectors especially in the internal layer to minimize multiple scattering that degrades the spatial resolution of the secondary vertex measurement. The front-end electronics will have to be compatible with the high-rate data acquisition of PHENIX, and the complicated integration of the system into the confined space surrounded by the time projection chamber and the magnet poles will have to be accomplished. Silicon microstrip detectors for the outer layers are being developed based on a design from the Instrumentation Division of Brookhaven National Laboratory. In a projective readout, track points can be reconstructed in "pixels" of 80 μm $\times$ 1 mm size. First prototypes were recently exposed to a test beam, and different front-end chips are being evaluated for their readout. Given the short time until the new vertex detector is needed in the experiment, at around the year 2005, the research on pixel detectors follows two paths. Monolithic pixel detectors are attractive for their potentially low thickness. Recent developments in the field are followed-up and improvements studied to increase their readout speed [5]. Hybrid pixel detectors as developed at CERN during the last decade have already reached a high level of sophistication [6] and are indispensable in the tracking systems of the next-generation experiments at the LHC. Attractive for PHENIX are the pixel detectors that will be used in the ALICE experiment [7], with a pixel size of 50 μm $\times$ 425 μm. The application in the inner tracker is very similar to what PHENIX would need, and the thinning of the intrinsically thicker hybrid approach is a concern for ALICE as well as for PHENIX. A technical collaboration between PHENIX institutions and ALICE-CERN is aspired that could result in the development and production of pixel detector modules suited for PHENIX. On a smaller scale, several members of a few PHENIX groups already gain experience with those detectors and participate in the NA60 experiment at CERN. NA60 uses ALICE pixel detectors and is building a vertex tracker for the measurement of prompt di-muon and charm production in proton and heavy ion beams at the CERN SPS [8].
Based on such silicon detectors, simulations of the expected performance of the vertex detector are performed. Both the barrel and the end-cap layers provide sufficient resolution to measure electrons and muons from semi-leptonic decays of D or B mesons. They will provide a single-track resolution of approximately 50 μm at the vertex. With a muon pair vertex resolution of about 130 μm, compared with the mean decay length of 1.1 mm, tagging of J/Ψ from B decays can be performed in the forward direction. In the barrel, D mesons can also be reconstructed via the D$\rightarrow \pi$K mode, and jet tagging will

be possible as required in polarized proton physics. The inner magnet coils can be operated to produce a high field in the vertex spectrometer region. The momentum resolution achieved with the combined tracking of vertex detector and time projection chamber in this field is almost as good as what is presently achieved with the central spectrometers of PHENIX, but covers a much larger angular acceptance.

5 Conclusion

With the baseline detector completed for Run-III, the PHENIX experiment has now reached full potential to explore the first phase of physics at RHIC. It will contribute to establish in detailed measurements the signatures of Quark Gluon Plasma creation in heavy ion collisions, and will measure the gluon polarization in the nucleon with polarized proton beams. In the next few years, increasing luminosities will allow to focus on rare electromagnetic probes and to distinguish spin assymmetries of different particle species. In the view of an upgraded RHIC machine that operates at much higher collision energy and luminosity, PHENIX prepares to enhance the capabilities of the experiment. Among the new detector systems foreseen, a vertex spectrometer upgrade is in the center of the interest. Vertex tracking is one of the important enhancements of PHENIX and will give access to exciting physics. We are designing a vertex detector that builds on silicon pixel and microstrip detector technology. The required performance has been identified, and we are working enthusiastically on the application of matching cutting-edge technologies to achieve that goal in the near future.

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